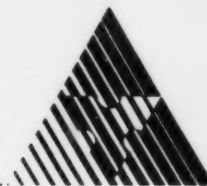


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Final Report by:

J.A. White & Associates Ltd., O/A DELTA ENGINEERING

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**PSYCHROMECHANICAL PROCESS
FOR MINE TAILINGS WASTEWATER**

March 31, 1989

MICROMEDIA

54 pp



Freeze Crystallization of Wastewater from Mine Tailings

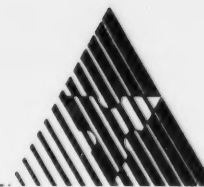


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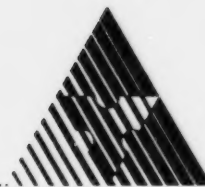
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EXECUTIVE SUMMARY

A pilot-scale experiment was conducted in February/March 1989 to investigate a psychromechanical process for treating effluent from mine tailings. The prime objectives of the experiment were to:

1. Verify separation of contaminants from the liquid effluent of mine tailings by freeze crystallization, and
2. Investigate the degree of reduction in acidity of the effluent from acid mine drainage (AMD) ponds by freeze crystallization.

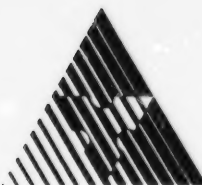
AMD liquid effluent was obtained from the Inco mine tailings treatment ponds in Sudbury, Ontario. The Whissel Drainage Pond near the village of Lively provided the source for the effluent. Machine snowmaking equipment was employed for the crystallization freezing of the effluent. Simple trays of effluent, exposed to ambient freezing temperatures, were also used to produce bulk ice samples to compare with the freeze crystallization process.

A significant degree of concentration of solids was achieved. Initial melt water (first 11% by weight) samples of up to 2,350 parts per million (ppm) of total iron were achieved. The final 61% weight melt water typically showed concentrations of less than 6 ppm. Heavy deposits of non-redissolvable solids precipitated from the treated effluent.

The AMD effluent was highly acidic (pH 2.57 to 3.6). The freeze crystallization process reduced acidity by better than an order of magnitude, raising the pH to 4.6 in the final 61% weight of the melt water.

The freeze crystallization/thawing process achieves higher levels of treatment as a function of time. Frozen effluent subjected to rapid thawing achieved only limited concentration of iron, and pH increases. Slower melting, simulating more natural climatic thawing processes, achieved significantly better results. Snow melting in natural conditions is exposed to ultra-violet radiation, and successive freeze and thaw cycles. These processes are expected to result in the migration of contaminants to the bottom of the deeper snow pack, resulting in improved levels of treatment.

The machine snowmaking process for treating effluent from acidic mine tailings appears to have considerable potential for commercial application. Separation of concentrated fractions and lower pH residues of melted treated effluents is economically achievable by use of machine snowmaking techniques and simple effluent run-off control measures.



SOMMAIRE EXÉCUTIF

En Février/Mars 1989, une expérience en laboratoire a été conduite pour étudier un processus de psychromécanique. Ce type de procédé est utilisé pour le traitement d'écoulement liquide à caractère acide provenant de résidus minier.

Les objectifs de l'expérience étaient:

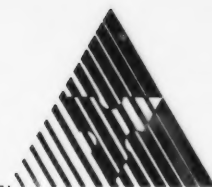
1. Observer la séparation des contaminants provenant des écoulements liquide. Cette séparation sera obtenue en cristallisant (par gel) le liquide à caractère acide.
2. Déterminer le niveau d'acidité des bassins d'acide minier provenant d'un système d'écoulement.

Le liquide provenant des bassins d'acide minier a été obtenu à Sudbury, Ontario, chez la firme INCO. Plus précisément, nous avons utilisé le bassin d'écoulement de Whissel. Il est situé près du village de Lively. Un système de fabrication de neige artificielle a été utilisé pour obtenir la cristallisation du liquide à caractère acide. Ainsi pour comparer le processus de cristallisation par le gel du liquide tout en utilisant le système de fabrication de neige avec un simple système d'écoulement, nous avons observé des cubes de glace qui ont été obtenus à partir de plateaux contenant du liquide à caractère acide qui étaient exposés à des températures sous le point de congélation.

Un niveau significatif de solide a été obtenu durant le dégel du premier 10% de la neige (ou glace) près de 1,985 particules par million de fer ont été obtenues. Le dernier 50% d'eau gelée démontrait une concentration de moins de 6 particules par million. De plus, nous avons obtenu un niveau élevé de précipités suite au traitement du liquide.

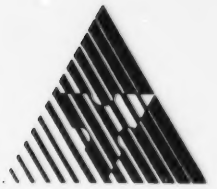
Le liquide provenant du système d'écoulement d'acide démontrait une concentration acide très élevée (pH 2.57 à 3.6). Suite au processus de cristallisation du liquide par le gel tout en utilisant le système à neige, le niveau d'acidité a été réduit par plus d'un facteur sur l'échelle d'évaluation du caractère d'acidité de la solution. Une augmentation du pH au niveau de 4.6 a été observée sur le dernier 50% d'eau dégelée.

On a pu observer que le processus de cristallisation par le gel obtient un niveau de performance plus élevé selon la fonction du temps. Par exemple, un liquide exposé à un dégel rapide atteindra un bas niveau de concentration en plus d'augmenter son niveau d'acidité. En ce qui a trait à une simulation plus normale, c'est-à-dire un dégel plus lent, on obtiendra des meilleurs résultats. Quand au dégel de la neige fabriqué à partir du liquide à caractère acide avec des conditions naturelles, exposée au ultra-violet, gel successif, différent cycle de dégel et avec la migration des contaminants solides au bas de la pile de neige, on



peut donc s'attendre à ce que la qualité du traitement du liquide à caractère acide atteigne un niveau plus haut que jamais.

Le processus utilisant le système à neige démontre un potentiel commerciale considérable pour le traitement d'écoulement liquide acide provenant de résidus minier. La séparation en fraction du concentré ainsi que l'obtention d'un pH moins élevé du liquide à caractère acide dégelé peut-être obtenus de façon économique par le processus de fabrication de neige artificielle et par simple contrôle d'un système d'écoulement pour la fonte des neiges. De plus, de la recherche additionnelle sur les niveaux de pH et sur des processus pour pouvoir diminuer le niveau d'acidité est recommandée comme suite à cette étude.



NOTE OF APPRECIATION

Delta Engineering wishes to thank Mr. Brian Bell and his staff at INCO for their generous co-operation. The provision of on-site laboratory space, storage facilities, a source of AMD effluent and the enthusiastic support of the INCO Environment Department staff helped the successful conduct of the on-site parts of the experiment, and are gratefully acknowledged.

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1.0 INTRODUCTION

1.1 BACKGROUND

The basic phenomenon of water purification by freezing of a liquid has been known for centuries. Desalination of seawater by freezing has been practised by early Inuits, and is in commercial use today. The application of freezing other liquids as a purification process is relatively new.

One purification process, the treatment of domestic wastewater (sewage) by a freeze crystallization process, was first postulated and investigated in the 1970's. In 1983, Delta Engineering conducted further experiments to investigate the "renovation and storage of sewage by conversion to snow". Testing showed that remarkably high levels of treatment were consistently achievable. Results were recorded in a report written by the Ontario Ministry of the Environment (MOE). The report substantiated an instantaneous rise in pH (+2.0) in the upper segment of the snow mound, and separation of chemical components held in solution in the effluent.

The report on this project, published in 1985 by MOE, has a restricted distribution, due to the proprietary interests of the company in the technology and results. A copy of the executive summary of the MOE report is contained in Appendix D of this report.

The freeze crystallization work in sewage treatment was considered to be of interest to other environmental wastewater problems, such as the treatment of effluent from mine tailings. Canada and other countries have billions of gallons of highly acidic effluent stored in lagoons serving abandoned and working mines. The Psychromechanical Process for Treating Mine Tailings project was, therefore, initiated to investigate chemical separation and pH treatment characteristics of freeze crystallization of effluent from mine tailings ponds.

1.2 PROJECT OVERVIEW

The Psychromechanical Process for Treating Mine Tailings was conceived as a research project to investigate alternative treatment methods for Acid Mine Drainage (AMD) from mine tailings.

A representative source of AMD was located at INCO in Sudbury, that presented an opportunity to conduct freeze crystallization experiments.

Discussions with the Scientific Authority for the project, Mr. Michel Filion, of CANMET, Energy Mines and Resources Canada (EMR), and INCO, resulted in a plan to make snow at the INCO site and to analyze melt water samples at the Chemical Testing Laboratory at EMR. The project consisted of five parts:

1. Freeze crystallization and natural freezing of bulk AMD effluent,
2. Melting of machine-made snow and natural ice samples,

3. Sample testing,
4. Data analysis and findings, and
5. Report.

Snowmaking equipment was assembled and tested on INCO property at the Whissel Drainage Pond site during the week of February 6th, 1989. Suitable weather (temperature and wind conditions) presented an opportunity for controlled snowmaking and collection of snow and ice on February 13th and 14th.

Two types of snow were produced: dry (20-24 lbs./cu. ft.) and moist (24-28 lbs./cu. ft.) and collected in plastic garbage containers. Since freeze crystallization treatment quality has been shown to be a function of time, three lots of both types of snow were saved for melting as follows:

1. QUICK MELT (2 barrels)
2. SLOW MELT (6 barrels)
3. AGED MELT (6 barrels)

QUICK MELT (1 to 2 days) was achieved by storing the garbage containers of snow in a heated (20° C) warehouse. SLOW MELT (5 to 7 days) was achieved by inserting the garbage containers into specially-constructed, insulated boxes. These boxes were then placed inside the warm warehouse. The SLOW MELT containers were fitted with centre-bottom drains and spigotts for drawing off liquid samples.

The AGED SNOW was stored outside in ambient conditions in the garbage containers, to simulate aging from natural climatic freeze/thaw cycles. The additional treatment effects from ultra-violet exposure of the snow to sunlight were not part of this laboratory-scale experiment.

The experimental procedures are described in more detail in Section 2 of the report. In brief, the procedures, both snowmaking and melting, proved to be very successful; however, some modification to the aging procedure and a need for field experiments to replicate truly natural aging treatment processes are indicated.



Inco - Copper Cliff Mill/Sudbury
Whissel Drainage Pond



Project Site - Pumphouse, Compressor and Support Facilities

2.0 TECHNICAL DISCUSSION

2.1 EXPERIMENTAL METHOD

The project to conduct research into a Psychromechanical Process for Mine Tailings Wastewater consisted of laboratory scale tests to investigate the dual phenomena of concentration of pollutants and increase in pH from freezing of AMD effluent. The primary treatment process investigated was freeze crystallization, using machine-snowmaking techniques. Testing of bulk freeze samples was conducted primarily as a reference base line and, secondly, in consideration of ice harvesting as a remote, but possible, alternative treatment method.

The experiment consisted of snowmaking and bulk freeze test runs, melting of snow and ice lots, collection of liquid and precipitate samples, laboratory tests, and analysis of results. This section of the report contains a description of the experimental method, with photographs of the test facilities, a graphical, pictorial, and text discussion of results, and preliminary considerations for commercial applications.

2.1.1 Snowmaking

Snowmaking equipment was set up adjacent to the pumphouse at the Whissel Drainage Pond at the INCO Copper Cliff Mill Site in Sudbury. INCO has a 600 acre area for collecting its AMD. An air/water snowmaking system was configured, consisting of:

- air compressor,
- submersible pump,
- snowguns and nozzles,
- hoses and fittings, and
- elevation scaffold.

The submersible pump was inserted in the main pumphouse sump, and drew its suction directly from the pond effluent. The snowgun was elevated on a scaffold to provide a flight path to promote freezing of the air/effluent mix as it descended into the target snow collection area.

A tarpaulin was spread underneath the garbage cans used for snow collection. Some snow from the tarpaulin was shovelled into the garbage containers to augment direct impact snow.

2.1.2 Effluent

The raw samples of AMD were drawn off the pump discharge. These raw effluent samples were tested on-site in the INCO laboratory by EMR staff members: Jack Hole, Section Head, Ores and Fire Assay Section, Mineral Sciences Laboratories, CANMET, and Rene Guillas, Laboratory Technician, CANMET. The raw effluent samples were also retained for later testing at EMR in Ottawa.

Samples of the pond ice were cut from the surface of the Whissel Dam Pond.



Scaffold for Mounting Snowgun



Snowmaking

A copy of an early analysis (1986) of the Whissel Pond effluent is contained in Appendix C. On-site testing of pH indicated the pond was somewhat less acidic (pH 3.5) in February 1989 than in May 1986 (pH 2.6).

2.1.3 Collection & Thawing of Snow and Ice *

* All references to percent snow melt in this report are weight percent.

Fourteen (14) garbage containers of snow were collected on February 14, 1989, as follows:

	<u>DRY SNOW</u>	<u>MOIST SNOW</u>
QUICK MELT	2	-
SLOW MELT	3	3
AGED MELT	3	3

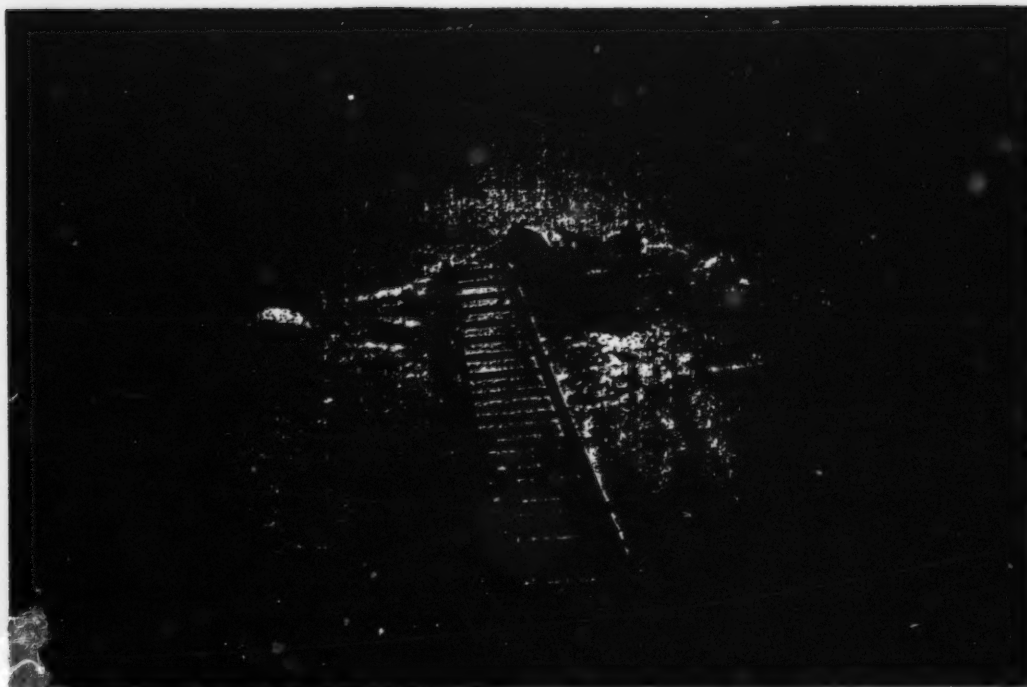
The QUICK MELT snow was transferred from the pond/snowmaking site on February 15th, and stored in the warm INCO warehouse, where it melted within 48 hours. The SLOW MELT snow was also transferred on February 15th, and stored in insulated containers in the warehouse. Approximately 40% of the SLOW MELT snow was melted by February 19th. The containers were then trucked to Delta's facilities in Ottawa, to continue the melting process, which was completed (100% melted) on February 24th, nine (9) days after melting began.

The AGED SNOW was left outside, after being manufactured on February 14th. It was transferred to Ottawa on February 19th, where it was placed on the roof of the Delta facilities to continue "weathering" outside. Three (3) containers of the AGED SNOW were transferred to the insulated containers, and three (3) were left in their plastic garbage containers.

The outside temperature in late February and early March was relatively cold. Very little melting took place on the roof. On March 14th, three containers of AGED SNOW were moved inside to accelerate the melting process, and the three in the insulated containers were left on the roof. Melting of the three barrels of snow continued inside heated Delta facilities to March 21st. Two (2) barrels were 100% melted within 48 hours, in uninsulated containers (1 dry snow, 1 moist) and one (1) barrel (moist) was transferred into a spigotted insulated container, where it took seven (7) days to complete the melting process.

Bulk ice was produced in accordance with the test plan on February 15th and 16th as follows:

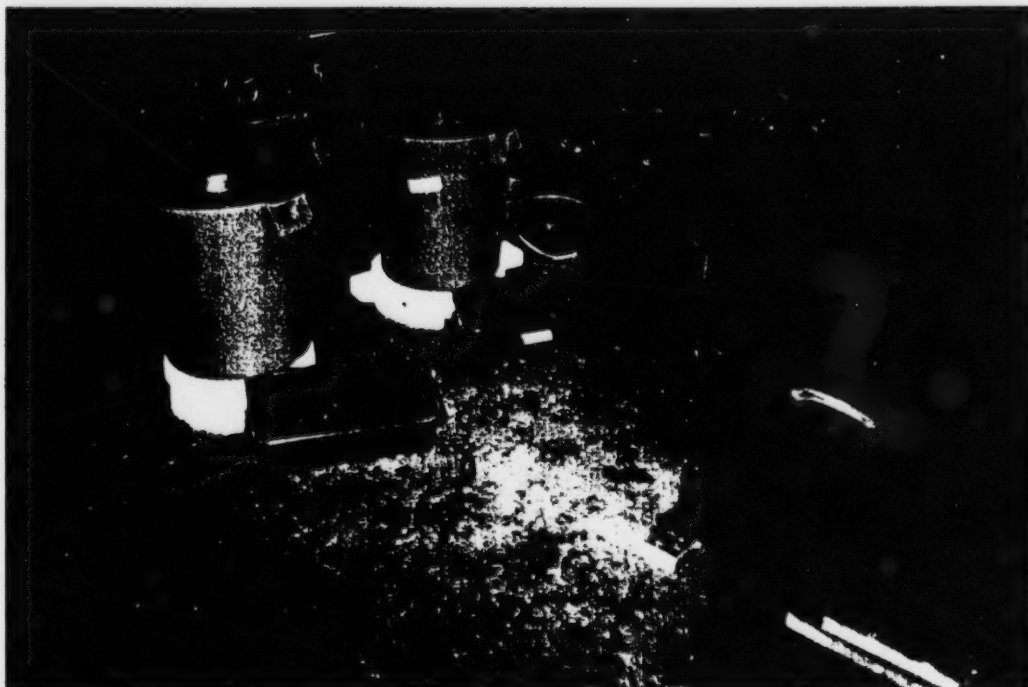
<u>Item</u>	<u>BULK ICE</u>	<u>Lot No.</u>
1.	2 tray of raw effluent	(AD-1, -2)
2.	Underlying unfrozen water from 1. combined and refrozen at -26° C	(AF)
3.	Ice from 1. melted and refrozen	(AE)



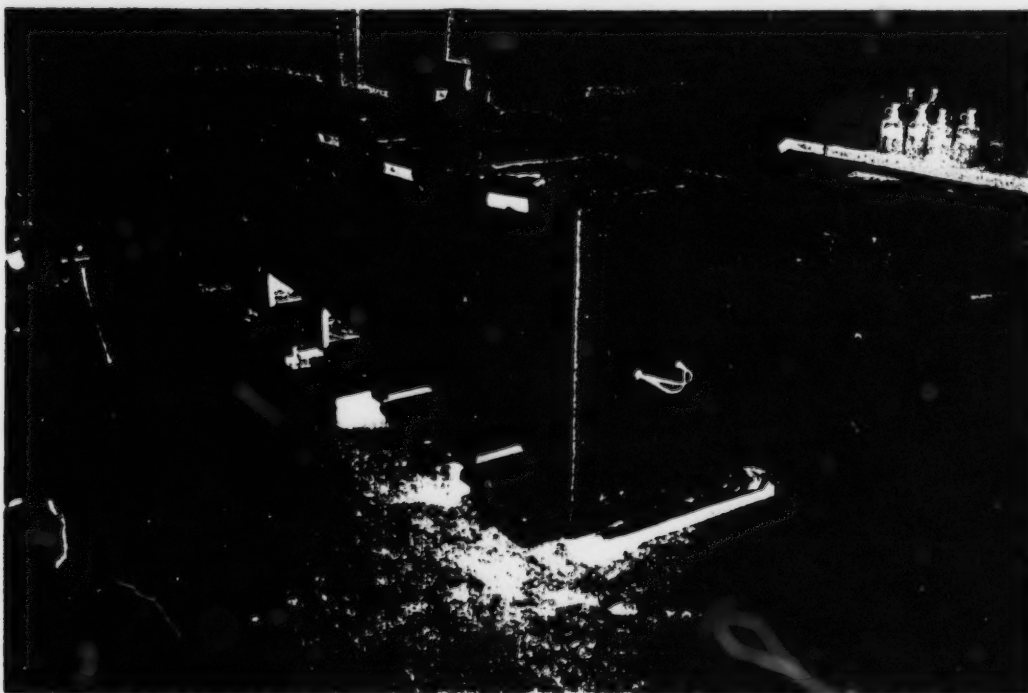
Pond Ice Sampling



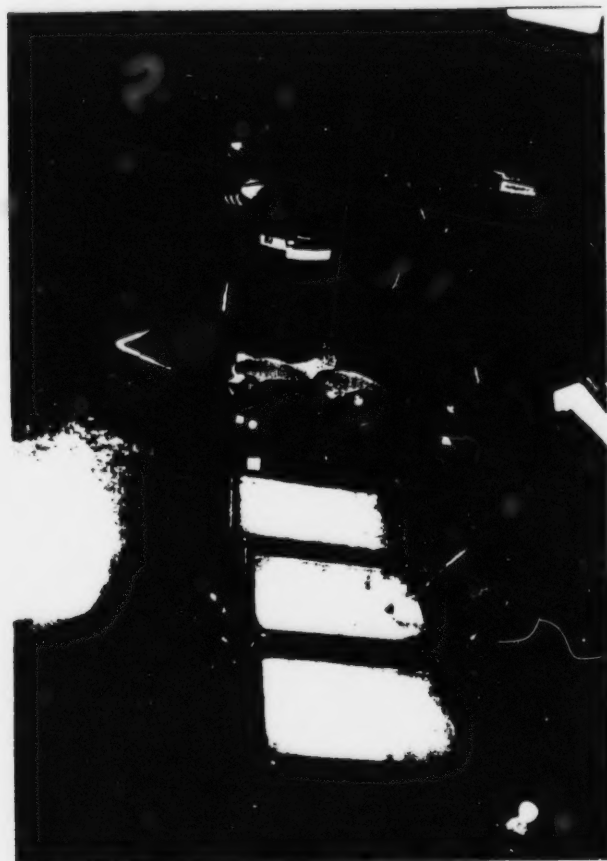
Snow Containers



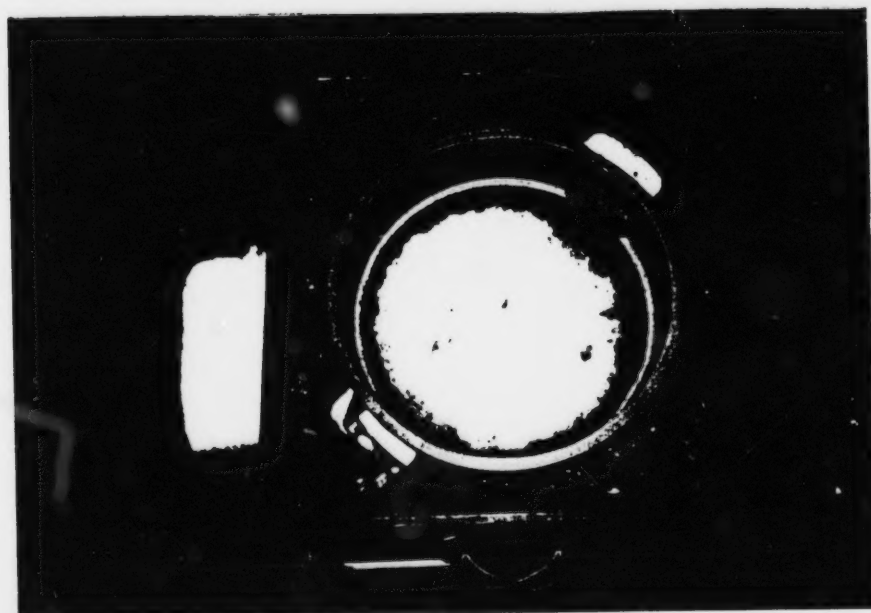
Quick Melt - Snow Containers and Melt Trays



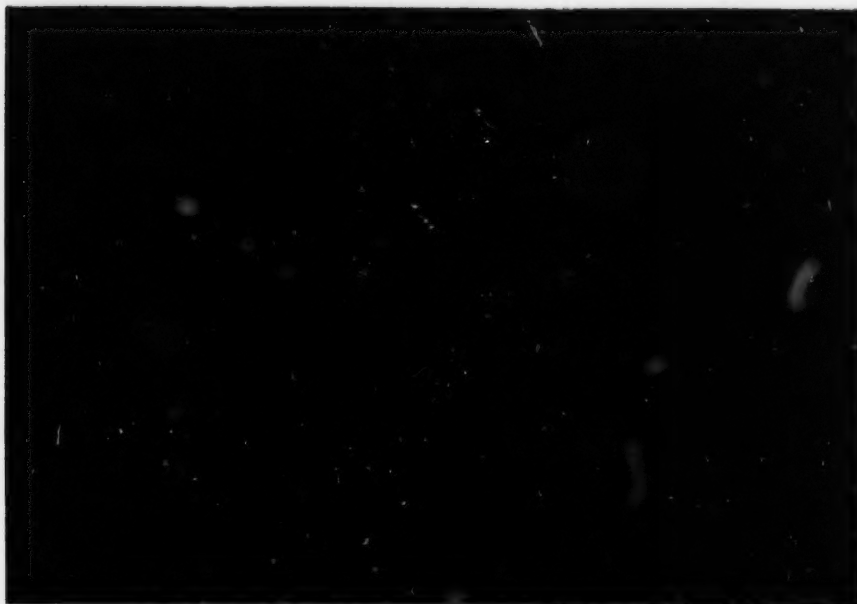
Slow Melt - Insulated Containers and Melt Trays



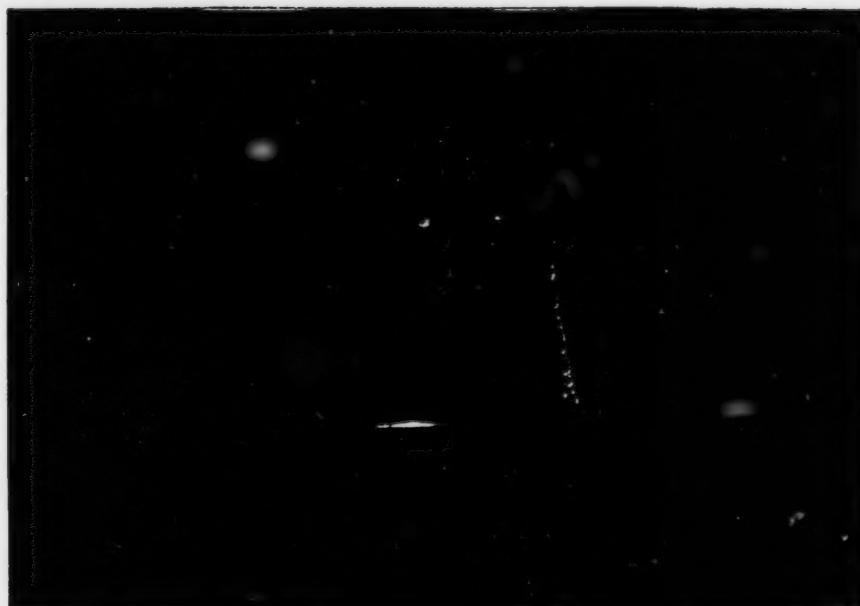
Bulk Ice - Thaw Trays



Slow Melt - Snow in Container



Slow Melt Sample and Bulk Ice



Bulk Ice - Refrozen Melt from Bulk Ice

Lot AE was aged by leaving it outside, and by subsequent melting indoors in the period March 14th to 20th. Lots AD-1 and AD-2 were partially frozen and the underlying concentrated liquid extracted as the "influent" for Lot AF. Ice from Item 1' was quick-melted to produce samples for testing, and as the "influent" for Item 3.

All bulk ice was manufactured in containers insulated on five sides with the top open, to ensure freezing took place top to bottom, simulating freezing of a pond.

2.1.4 Sample Collection

Liquid samples were drawn from all snow containers at the following cumulative weight proportion of melt: 10%, 15%, 25%, 50%, and 100%. The 10% sample represents the first 10% of the melt. The 15% sample is actually the next 5% and the 25% sample is the next 10% of the snow melt. The 50% sample is the melt water between the 25% melt point and the 50% melt point. The 100% sample is the last half of the melt water. The actual average weights which were obtained were 11%, 17%, 28%, 39%, and 100% (for the slow melt samples) respectively.

Samples were collected in one (1) litre plastic laboratory bottles, capped, and labelled in accordance with a coded scheme identifying, a) lot number, and b) percentage melt point.

All snow lots were weighed. Liquids extracted were then subsequently weighed to find the approximate melt percentage point at which the sample had been extracted.

QUICK MELT snow was melted in uninsulated containers. Melt run-off was extracted from a simple hole in the bottom, where it drained into a catch tray below the hole.

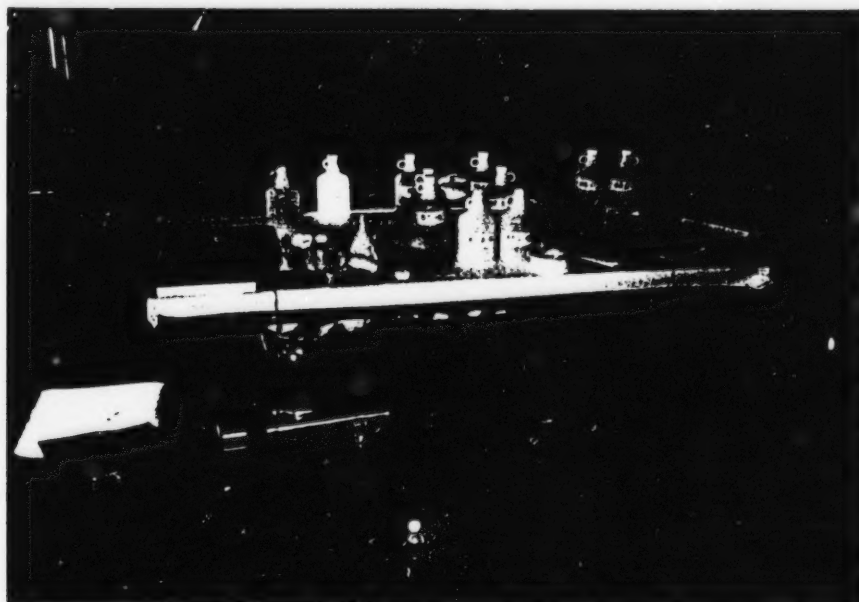
SLOW MELT snow was melted in insulated containers with center-drilled holes, draining run-off via a tube and spigott into catch trays underneath the container. This process worked extremely well inside; however, freezing in the tube above the spigott obviated the use of this technique for the aging snow outside.

AGED SNOW was melted in three standard plastic garbage containers in insulated boxes with center-drilled holes. Melt run-off was allowed to drain freely from the holes into catch trays. The three AGED SNOW containers which were moved inside to accelerate melting were decanted to allow accumulated melt run-off to be extracted at the specified melt points.

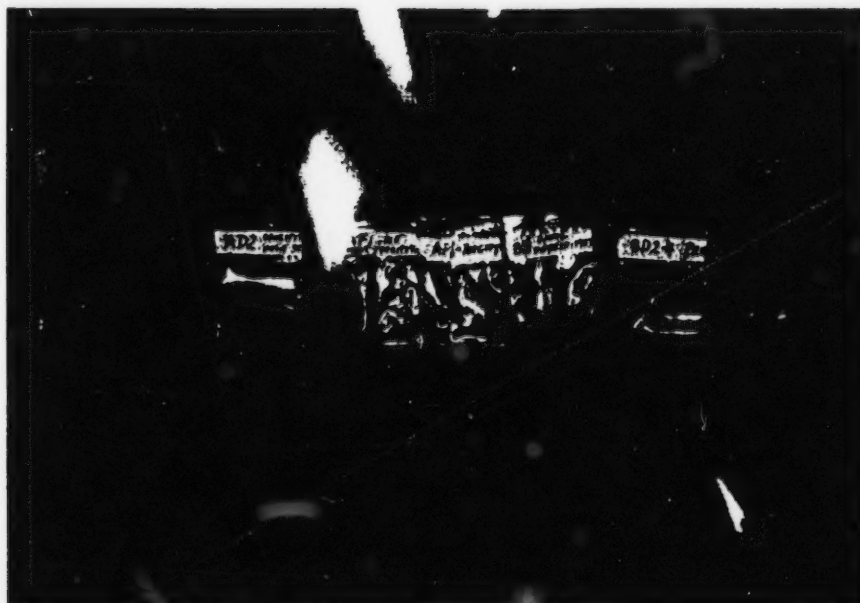
2.1.5 Sample Presentation and Analysis

Analysis of pH and total iron were selected as representative of a wider spectrum of chemical changes occurring in the treated effluent. Visual examination of samples showed significant settling of solids. Agitation of samples of concentrated fractions of post-freeze liquid showed subsequent rapid settling of the precipitated solids.

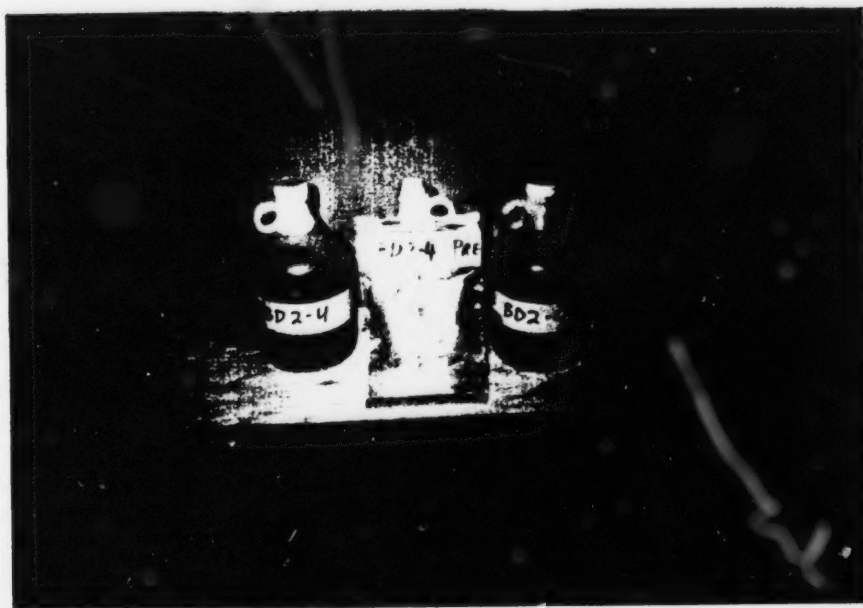
Test results are discussed in Section 2, and presented in tabular form in Appendix B.



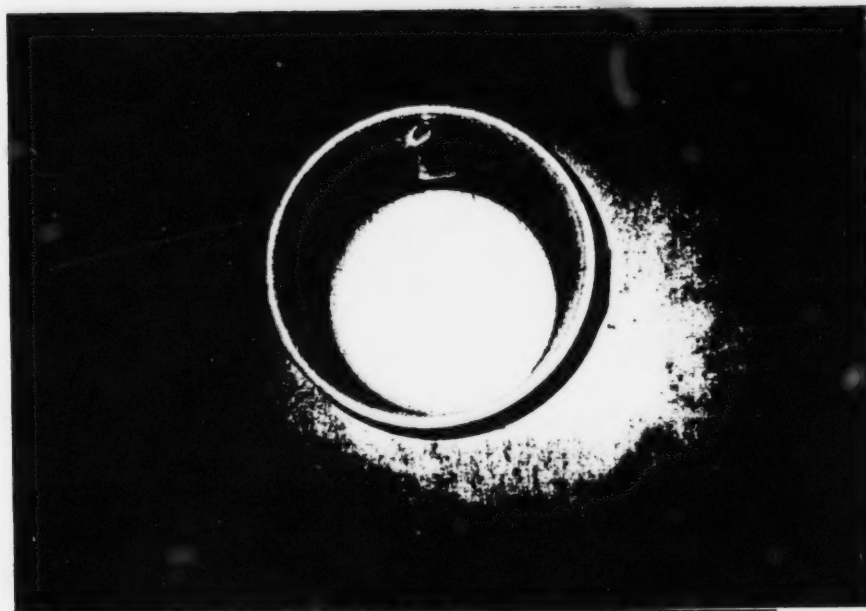
Sample Collection



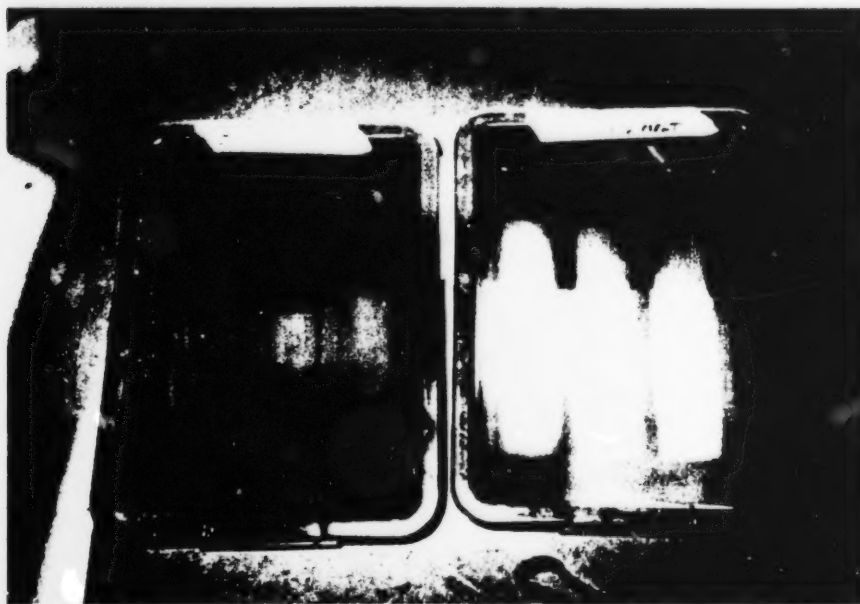
Precipitate Collection



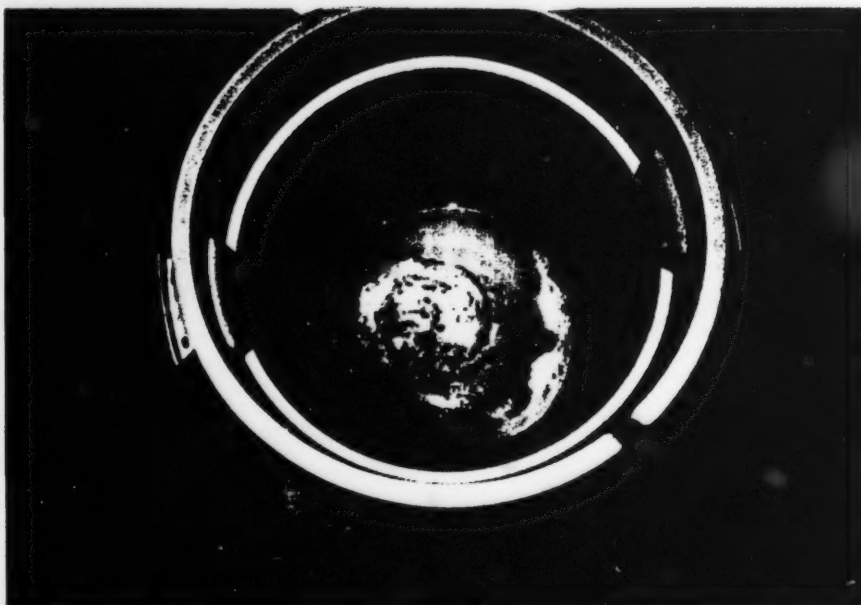
Coded Sample Collection - 1 Litre Lab Bottles



Aged Snow Melt



Settled Precipitate from Slow Melt



Residue from Slow Melt Container

Testing was conducted at two stages in the project. Initial on-site testing in the INCO laboratory was conducted by EMR personnel to give quick melt results as initial trend indicators. Final sample analyses were conducted at the CANMET laboratory in Ottawa by the same EMR personnel. All samples were retained in new 1 litre plastic bottles. Samples of raw influent were immediately analysed for total iron and pH.

The test procedures were as follows:

Iron - Fe:

A 10 ml aliquot was obtained from an agitated sample and immediately transferred to a 100 ml volumetric flask. The sample was acidified with 4 ml of hydrochloric acid. Measurements were run on an atomic absorption spectrophotometer for total iron. Comparisons were made with a calibration curve prepared from standards, and results were back-calculated to concentrate level.

At INCO, colourimetric analysis, requiring higher (X 2) levels of dilution, was used for Fe measurement.

Acidity - pH:

Acidity was measured using an electronic pH meter, with a combination gel pH electrode. pH measurement is standardized against buffers with pH levels of 2, 4, 7, etc..

Blind duplicate analyses were conducted on selected samples for control purposes.

2.2 RESULTS

2.2.1 Samples

Test results have been grouped into the same categories as the project tests; namely,

QUICK MELT
SLOW MELT
AGED MELT
BULK ICE

Test results are shown by category in Tables 1, 2, & 3, below and in Appendix B as recorded on the EMR Chemical Laboratory Analysis forms for Project 308601, Report B89-1434 to 1437 and B89-1445.

Five tables contain the test data labelled as follows:

TABLE 1	SNOW MELT
TABLE 2	BULK ICE
TABLE 3	RAW EFFLUENT (AMD) (Influent for all experiments)
TABLE 4	INITIAL WEIGHT OF SNOW IN CONTAINERS
TABLE 5	PERCENT MELT BY WEIGHT

TABLE 1 SNOW MELT - Total Iron and pH

A. QUICK MELT (Dry Snow)

% Melt	Lot 1		Lot 2	
Weight	(BD-1)		(BD-2)	
	pH	Fe, mg/l	pH	Fe, mg/l
10	3.21	540	2.99/2.97	718
15	3.18	636	3.07	666
25	3.15	832	3.05	586/596
50	3.23	590/579	3.14	562/560
100	3.33/3.26	73.80/72.50	3.16	69.70/69.25

B. SLOW MELT (Dry Snow)

% Melt	Lot 3		Lot 4		Lot 5	
Weight	(BB-1)		(BB-2)		(BB-3)	
	pH	Fe, mg/l	pH	Fe, mg/l	pH	Fe, mg/l
10	3.10	1798/1864	3.05	2350	3.04	1980
15	3.19	1126	3.28	758	3.14/3.04	1138
25	3.39	399	3.45	282/271	3.48	244
50	3.75	69.40/66.75	3.81/3.66	69.20	3.92	47.90
100	4.36	7.20	4.57	3.90	4.50	4.30

C. SLOW MELT (Moist Snow)

% Melt	Lot 6		Lot 7		Lot 8	
Weight	(BC-1)		(BC-2)		(BC-3)	
	pHh	Fe, mg/l	pH	Fe, mg/l	pH	Fe, mg/l
10	3.06	1960	3.04	1930	3.01	1985
15	3.15	1232/1265	3.13	1186	3.10	1292
25	3.36	410	3.24/3.16	654/644	3.26/3.20	549
50	3.36	112	3.59	103.3	3.89	30.70
100	4.38	6.90	4.38	4.40	4.54/4.35	2.20

TABLE 2 BULK ICE - Total Iron and Acidity Test Results

A. POND SURFACE ICE

	<u>Lot 9 (AB-1)</u>		<u>Lot 10 (AB-2)</u>	
	<u>pH</u>	<u>Fe, mg/l</u>	<u>pH</u>	<u>Fe, mg/l</u>
Top Ice Layer	2.98	13.6	-	-
Bottom Ice Layer	-	-	3.01	36.8

B. FROZEN EFFLUENT (Manufactured Ice)

	<u>Lot 11 (AD-1)</u>		<u>Lot 12 (AD-2)</u>		<u>Lot 13 (AD-3)</u>	
	<u>pH</u>	<u>Fe, mg/l</u>	<u>pH</u>	<u>Fe, mg/l</u>	<u>pH</u>	<u>Fe, mg/l</u>
Ice Melt	2.92	124	2.97	161.5	-	-
Sub-Surface						
Liquid Mixed						
from AD-1 &						
AD-2	-	-	-	-	2.78	473

-(Unfrozen liquid below ice surface)

C. FROZEN SUB SURFACE LIQUID FROM LOT 13 (AD)

	<u>Lot 14 (AF-1)</u>	
	<u>pH</u>	<u>Fe, mg/l</u>
Melted Surface Ice (2")	3.12	317
Precipitate	2.42	972
Liquid	2.76	1448/1444

TABLE 3 RAW EFFLUENT (AMD)

	<u>Influent For All Tests (BCO)</u>	
	<u>pH</u>	<u>Fe, mg/l</u>
Ottawa Measurements: (March)	2.57	314
On Site Measurements: (February)	3.7	360
	3.5	320
	3.41	300

TABLE 4 INITIAL WEIGHT OF SNOW

		<u>GROSS</u> (kg)	<u>CONTAINER</u> (kg)	<u>TARE</u> (kg)
<u>QUICK MELT</u>				
	BD-1	25.70	2.40	23.30
	BD-2	31.80	2.40	29.40
<u>SLOW MELT (Dry)</u>				
	BB-1	26.45	2.35	24.10
	BB-2	29.80	2.35	27.45
	BB-3	23.15	2.40	20.75
<u>SLOW MELT (Moist)</u>				
	BC-1	25.95	2.40	23.55
	BC-2	32.10	2.40	29.70
	BC-3	36.20	2.40	33.80
<u>AGED MELT (Dry)</u>				
	CE-1	27.60	2.40	25.20
	CE-2	32.00	2.40	29.60
	CE-3	27.00	2.40	24.60
<u>AGED MELT (Moist)</u>				
	CF-1	33.20	2.40	30.80
	CF-2	32.45	2.40	30.05
	CF-3	33.60	2.40	31.20

TABLE 5 PERCENT MELT BY WEIGHT

READING #		1	2	3	4	5	NET
APPROX % MELT		10	15	25	50	100	WT
Individual Melt wt (Kg)/cumulative %							
QUICK	BD-1	2.8/ 12.0%	0.8/ 15.9%	2.2/ 24.9%	4.65/ 44.8%	11.65/ 100% (total 22.1)	23.30
	BD-2	2.85/ 9.6%	1.65/ 15.3%	2.25/ 23.0%	7.95/ 50.0%	13.10/ 100%	29.40 (27.80)
SLOW (Dry)	BB-1	2.50/ 10.4%	1.20/ 15.4%	3.00/ 27.8%	3.30/ 41.5%	9.40/ 100%	24.10 (19.4)
	BB-2	2.90/ 10.6%	2.15/ 18.4%	2.60/ 27.9%	*1.45/ 33.2%	*10.65/ 100%	27.45 *19.75
	BB-3	2.55/ 12.3%	1.70/ 20.5%	2.60/ 33.0%	3.10/ 48.0%	7.75/ 100%	20.75 (17.70)
SLOW (Moist)	BC _r 1	2.30/ 9.9%	1.30/ 15.4%	3.00/ 28.1%	3.20/ 42.0%	9.85/ 100%	23.35 (19.65)
	BC-2	2.95/ 9.9%	1.55/ 15.2%	2.95/ 25.1%	2.80/ 34.5%	13.75/ 100%	29.70 (24.0)
	BC-3	3.40/ 10.0%	1.70/ 15.1%	3.40/ 25.1%	2.75/ 33.8%	18.45/ 100%	33.80 (29.70)

* Data unreliable due to mixing and confusion in melt tray weights.

2.2.2 Snowmaking Conditions

Ambient temperatures at time of making snow on February 14 were as follows:

	<u>Dry Bulb</u>	0°C	<u>Dew Point</u>	
2100 2/14	-7		-14	(Environment Canada)
2200 2/14	-8		-13	
2300 2/14	-8		-13	
2400 2/14	-7		-12	
0100 2/15	-7		-12	

The snowmaking equipment operated as follows:

	<u>Effluent Flow (gpm)</u>	<u>Air Flow (SCFM) at 110psi</u>	<u>Air Water Ratio</u>
Dry Snow	3.0	72	24:1
Moist Snow	5.5	68	12.4:1

Bulk ice was made on February 15/16,
with temperatures dropping to a low of -26°C.

2.3.1 Showmaking

Statistical analysis of the snowmaking data was done using STATGRAPHICS, Version 2.1, running on a PC.

Multifactor analysis of variance was performed on the data by treatment (i.e., dry, moist, and quick), and by melt fraction (10%, 15%, 25%, 50%, and 100%) for both pH and concentration of total iron. This analysis revealed that there are significant differences ($p < 0.0002$) for both response variables by treatment and melt fraction. A confidence interval multiple range test revealed that there is no significant difference between the treatments, dry and moist, for both pH and iron. This is illustrated in Figures 1 and 2. These figures also show the decline in total iron concentration from the 10% melt fraction to the 100% melt fraction and the rise in pH over the same range. Note that the quick melt treatment shows no such trends, and is different from the other two treatments.

Further analysis was conducted on the pooled data from the dry and moist treatments. This was done to increase the number of data points for each melt fraction.

Figure 3 shows the decline in total iron from average 2,006 ppm for the first 11% of melt to 4.8 ppm for the last 61% of melt (the 100% fraction). The 50% and 100% melt fractions are not significantly different from each other, and the mean of these two data points (weighted on a mass basis) indicates that over 72% of the melt water would be less than 15 ppm, average total iron concentration. This compares with the 314 ppm of total iron found in the test effluent.

Figure 4 shows the increase in pH (decrease $[H^+]$) from average 3.05 for the first 11% of melt to 4.4 for the last 61% of melt (the 100% fraction). The 10% and 15% fractions are not significantly different from each other; however, they do indicate a general upward trend in pH. With the 25%, 50%, and 100% fractions, the increases in pH are significant. The weighted average of the 50% and 100% fractions indicates that 72% of the melt water has an average pH of greater than 4.33. This is an increase in pH of over 1.5 units, compared with the effluent that was tested at the EMR lab in Ottawa. This is the equivalent of a 1.5 order of magnitude reduction in hydronium ion concentration.

2.3.2 Bulk Ice

The test program called for only a limited number of tests of bulk ice; as a consequence, no statistical analysis has been attempted. The data show that the bulk ice process has less effect on pH and total iron concentration than the freeze crystallization snowmaking process.

The data, in fact, show that an increase in acidity of the surface ice is achieved, and some degree of expulsion of total Fe is achieved, approximately half as much as the QUICK MELT snow.

Figure 1: 95% Confidence Intervals for total Iron (Fe) ppm by melt fraction and treatment ($n=3$). The horizontal bar represents the average value for a particular sample and the vertical lines represent the range in which we can be 95% sure that the actual "population" average is located. Each group of the three Confidence Intervals represents a particular melt fraction sample - 10%, 15%, 25%, 50% and 100% from left to right. Within each group the leftmost confidence interval is for dry slow melt snow, the middle confidence interval is for moist slow melt snow and the rightmost one is for quick melt snow.

95 Percent Confidence Intervals for Total Iron by Melt Fraction and Treatment

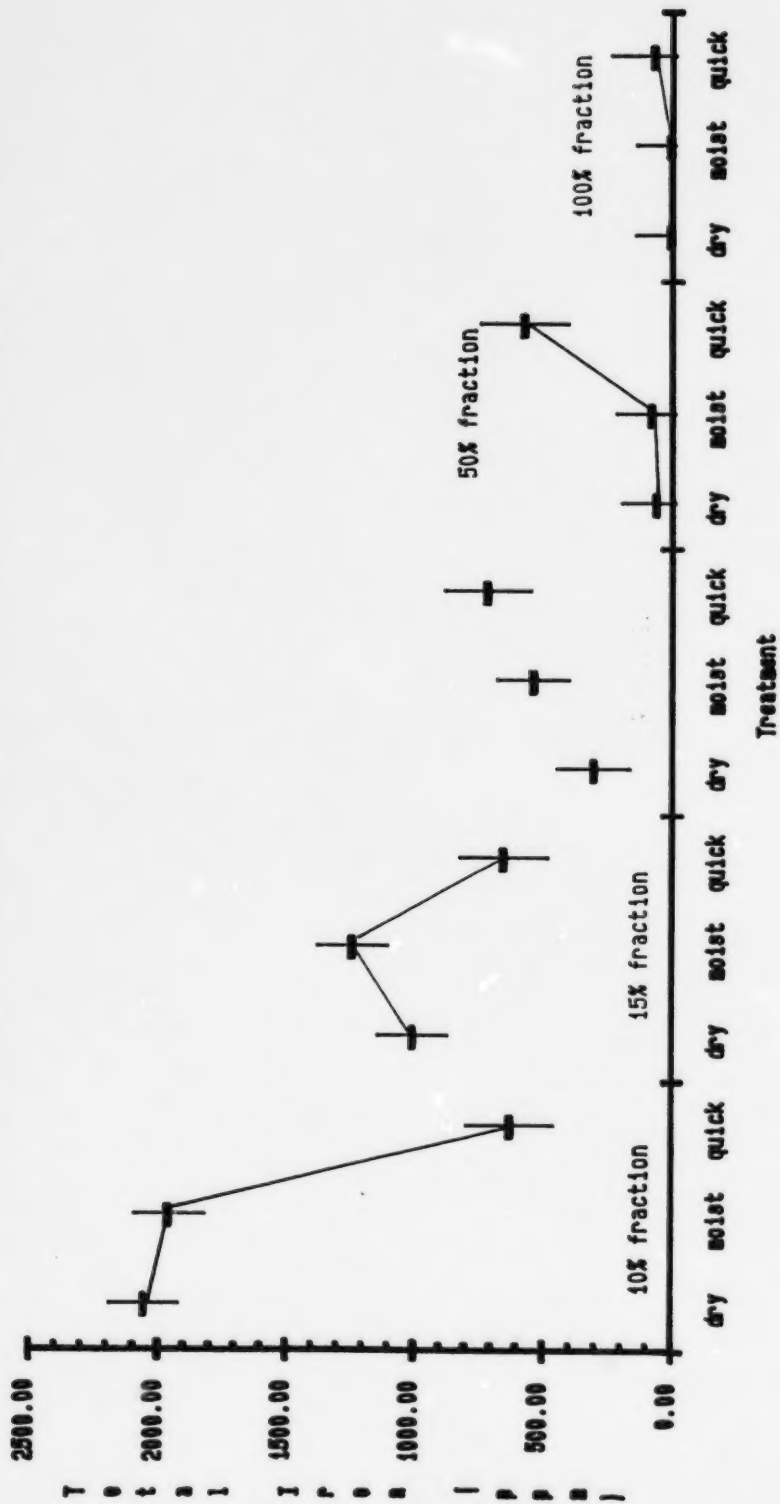


Figure 2:

95% Confidence Intervals for pH by melt fraction and treatment ($n=3$). The horizontal bar represents the average value for a particular sample and the vertical lines represent the range in which we can be 95% sure that the actual "population" average is located. Each group of the three Confidence Intervals represents a particular melt fraction - 10%, 15%, 25%, 50% and 100% from left to right. Within each group the leftmost confidence interval is for dry slow melt snow, the middle confidence interval is for moist slow melt snow and the rightmost one is for quick melt snow.

Figure 3: 95% Confidence Intervals for total Iron (Fe) ppm (dry and moist fractions pooled; $n=6$) by meltfraction. The horizontal bar represents the average value for a particular sample and the vertical lines represent the range in which we can be 95% sure that the actual "population" average is located.

95 Percent Confidence Intervals for Total Iron (ppm) by Melt Fraction

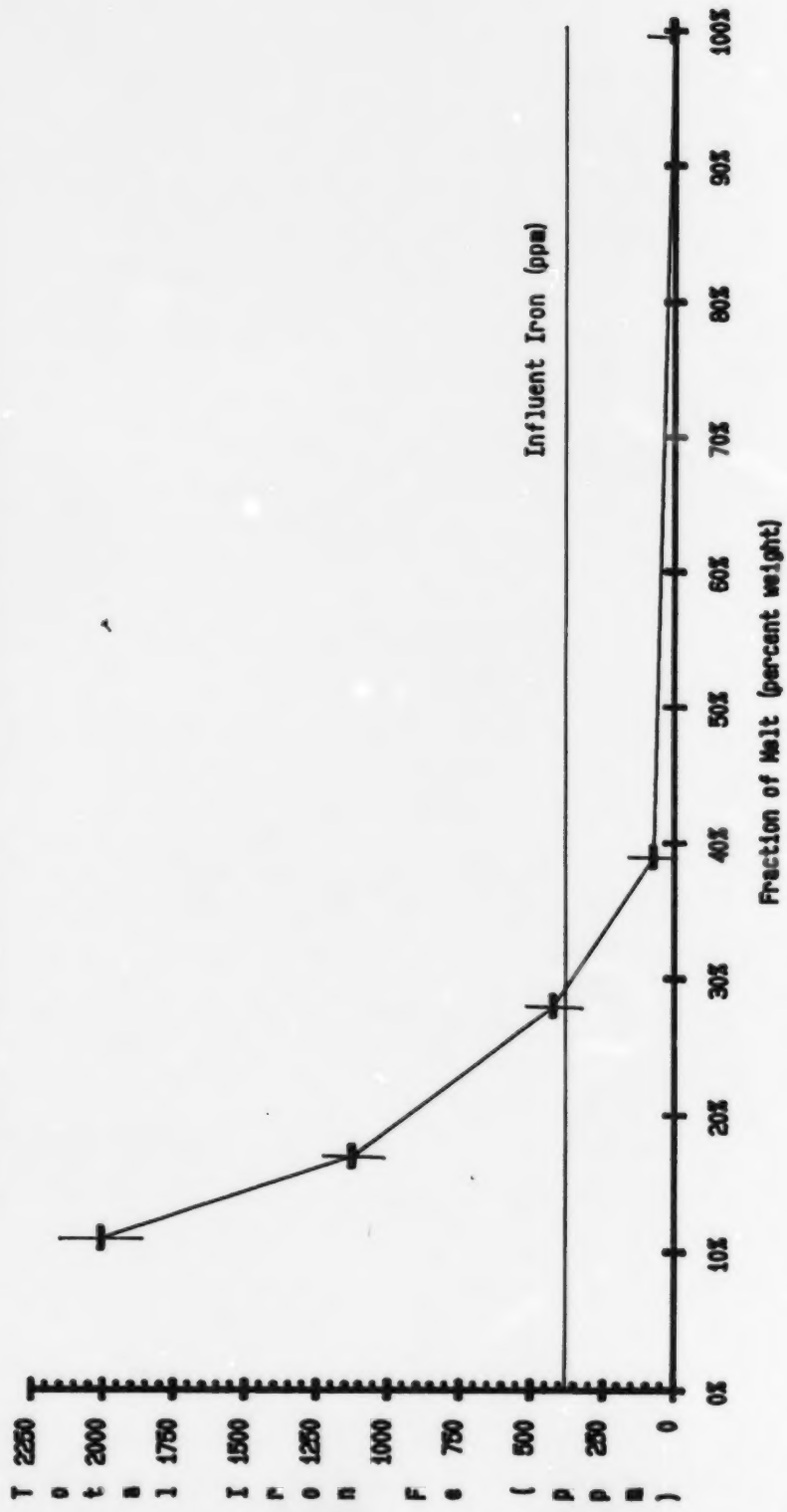
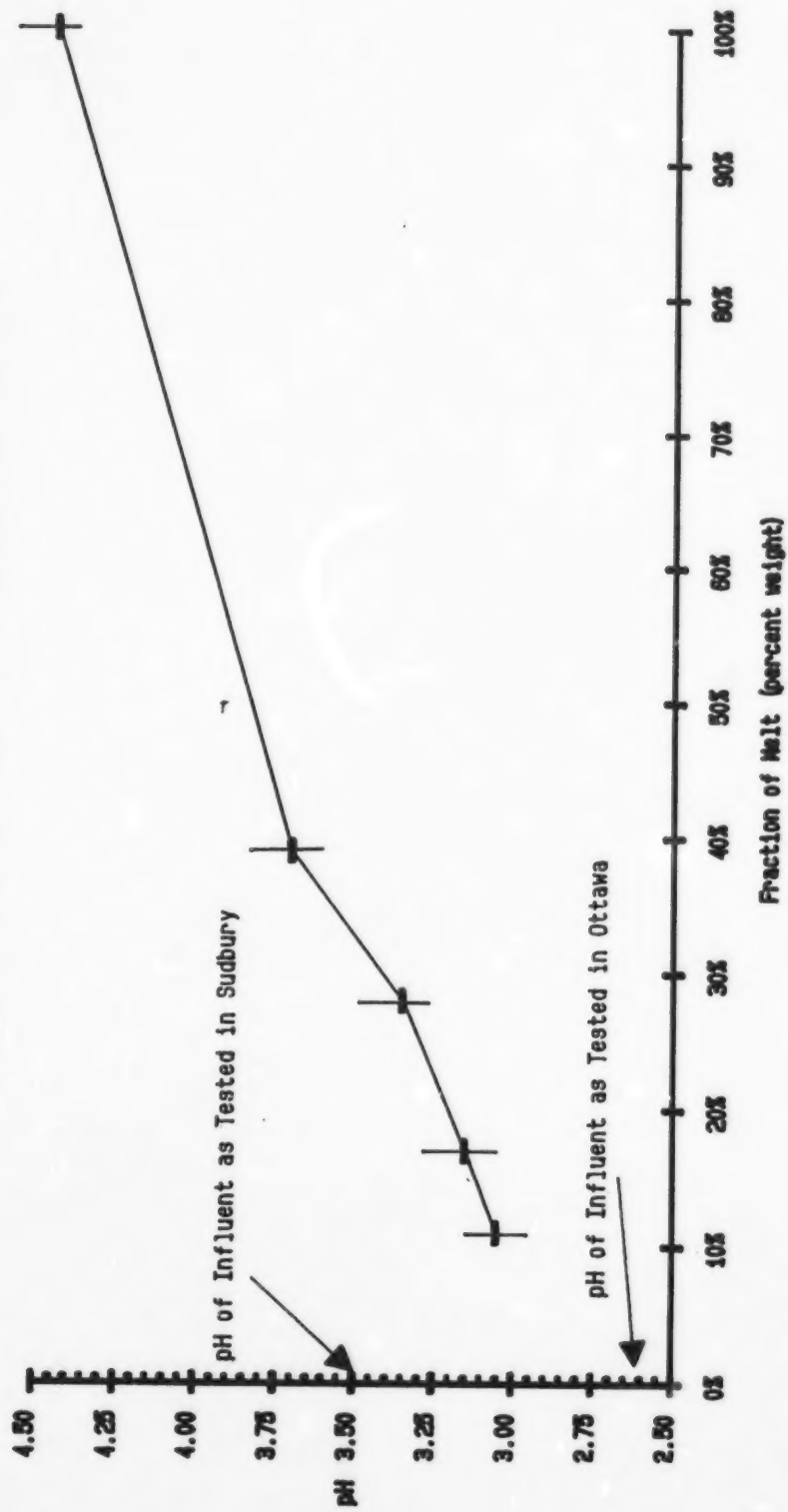


Figure 4: 95% Confidence Intervals for pH (dry and moist fractions pooled; $n=6$) by melt fraction. The horizontal bar represents the average value for a particular sample and the vertical lines represent the range in which we can be 95% sure that the actual "population" average is located.

95 Percent Confidence Intervals for pH Malt Fraction



The primary application envisioned for the psychromechanical treatment of wastewater from mine tailings is the freeze crystallization of effluents and seepages at operating mine sites in Canada. Harvesting of bulk ice, while conceptually a possibility, was investigated with only limited testing in this project, so as not to ignore it as an alternative, but more as a control comparison for snowmaking.

The commercial application of snowmaking is projected as follows:

1. A snowmaking plant (fixed or mobile unit) is sited at the mine.
2. Winter-time snowmaking and concentration.
3. Summer-time recycle of snow melt to the mill process.

The snowmaking stage concentrates the wastewater, returns this concentrate to the primary pond, and allows separation of the purer fraction into a separate pond for a supply of purified water as recycled feed water for the mill process.

Snowmaking is now a scientifically-based discipline, in which the efficiencies of snowmaking equipment and the engineering design of the plant have major capital and operating cost implications. Moist snow is somewhat cheaper to make than dry snow, and can also be made over a longer season, even at the marginal temperature extremes in the Fall and Spring.

The initial test results showing that treatment using moist snow is effectively equivalent to dry snow has a positive operating cost implication. Field tests are needed to verify this pilot-scale test result.

The operational concept for commercial application requires a cost analysis and comparison with existing methods used in treatment. As an example, a 2,000 GPM pumping and snowmaking system would require approximately 35 acres of land, with a snow pile 50 feet deep, to absorb half a billion gallons of wastewater per year (assuming 150 snowmaking days).

A typical operating plant with up to 2,000 USGpm capacity would cost in the range of 1 to 1 1/2 million dollars (\$ Canadian), including a pumphouse and control building. Operating costs are very much dependant on local electrical power rates for consumption and demand. Typical operating costs for the 2,000 USGpm plant and 15,000 SCFM air capacity and 150 days operation are approximately \$300,000, excluding labour costs. Since the plant is highly automated, manpower requirements would be extremely low, perhaps averaging 0.5 man years/year. Periodic testing requirements would be additional, and are not included in the costs stated.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 THE PROJECT

The project provided an opportunity to test and verify alternative processes for treating acid mine drainage (AMD) from mine waste sites. Earlier work by Delta Engineering had investigated and reported on freeze crystallization using machine-snowmaking techniques. Freezing of domestic wastewater (sewage) has been proven to be an extremely effective treatment process, with potential application in treating industrial wastewaters.

The primary aim of the project was to investigate acidity and contaminant separation effects in experimental tests of snowmaking from acidic mine tailings wastewater effluent.

3.2 INTERPRETATION OF RESULTS

The primary aim was achieved, together with a secondary objective of investigating effects caused by natural ice production. A six-fold concentration of contaminants was achieved in the first 10% of snow melt, indicating initial run-off could be piped to a concentration tank or pond, while purer liquid in the final melt fraction is retained for use as process-recycle water or further treatment and discharge. The final melt fraction reduced contaminant concentrations by a factor of 50.

Concentration effects from ice were considerably less than that of snow, confirming that the ice process is not a viable treatment technique in its own right. Concentration levels of contaminants, as represented by testing for total iron content, proved to be a function of "melting quality". "Melting quality" is defined as both a time function and a mode function of melting. The higher the "melt quality", the greater is the degree of contaminant concentration. (See Recommendations, 3.4, below).

3.3 DISCUSSION

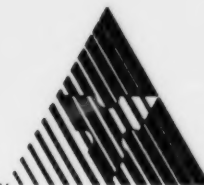
The phenomena of concentration of contaminants and increase in pH were predicted from related wastewater snowmaking experiments. The degree of concentration and change in acidity level achievable, however, are of primary interest in judging the potential for freeze crystallization as an alternative treatment process.

Test results presented in Section 2 of the report show significant increases of total iron concentration and pH.

High "melt quality" in a laboratory-scale test is difficult to replicate. Experience with field tests of snowmaking have shown that contaminant concentration effects are a function of height of the snow mound. Exposure to ultra-violet, successive freeze/thaw, run-off, the mixing of natural, clean snow and rain, and the flushing effect of the downward migration of particulate matter to the bottom of the snow mound, combine to provide additional treatment levels.

A snow mound of 50 feet in height takes a considerable time to melt. This allows additional time for nature's forces to apply a final polish to the contaminant and pH levels in the latter fractions of melt.

Further work to examine the effects of deeper snow mounds and natural climatic aging forces appears warranted to explore data in the critical purified fraction. Field tests to replicate and measure effects of natural forces are recommended as a follow-on stage to the laboratory-scale tests undertaken thus far.



APPENDIX A
DATA COLLECTION SCHEME

PSYCHROMECHANICAL PROCESS FOR TREATING MINE TAILINGS

DELTA ENGINEERING CONTRACT #88-507

DSS CONTRACT NUMBER 23440-8-9204/01-SQ

TEST PROCEDURE

Samples of effluent will be collected and analyzed after bulk freezing and snowmaking processes to establish the degree of separation of contaminants in AMD from the INCO Whissel drainage pond. Reference samples will also be collected in order to compare before and after results.

Three types of "frozen" products will be generated:

- A. Bulk Freeze Ice,
- B. Snow, and
- C. Aged Snow.

Additional tests of the bulk ice will be conducted to test a repetitive freeze second iteration purification process. A second sample bottle of liquid will be drawn off the 10 and 15% melt to test for precipitates by filtering.

The test runs are as follows (Note: All analysis will be conducted as blind laboratory tests):

A. Bulk Freeze Ice

		<u>No. of Samples To Be Taken</u>
AA (1,2,3)	Raw effluent sample	3
AB (1,2)	Pond ice sample (top ice/bottom ice)	2
AC (1)	Freeze tray to bottom, then melt	
	Sample melt water, precipitate	2
AD (1,2)	Freeze raw effluent in trays to 2 inches ice.	
	Sample - ice melt	2
	- concentrated liquid	2
	- precipitate	2
AE (1)	Melt ice from AD (1,2,3). Combine in 1 tray and freeze to 2 inch thickness.	
	Sample - ice melt	1
	- concentrated liquid	1
	- precipitate	1
AF (1)	Transfer liquid from AD (1,2,3) to clean trays and freeze to 2 inch ice thickness.	
	Sample - ice melt	1
	- concentrated liquid	1
	- precipitate	1
Bulk Ice Subtotal - Samples		<u>19</u>

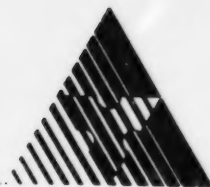
B. Snow

		<u>No. of Samples To Be Taken</u>
BB	Dry Snow	
BB0	Raw influent	1
BB (1,2,3)-1	Melt 10% - 2 bottles of each	3
BB (1,2,3)-2	Melt 15% - 2 bottles of each	3
BB (1,2,3)-3	Melt 25%	3
BB (1,2,3)-4	Melt 50%	3
BB (1,2,3)-5	Melt 100%	3
		<u>16</u>
BC	Medium Wet Snow	
BC0	Raw influent	1
BC (1,2,3)-1	Melt 10% - 2 bottles of each	3
BC (1,2,3)-2	Melt 15% - 2 bottles of each	3
BC (1,2,3)-3	Melt 25%	3
BC (1,2,3)-4	Melt 50%	3
BC (1,2,3)-5	Melt 100%	3
		<u>16</u>
BD	Quick Snow Melt (dry = 1/medium-wet = 2) (On-site test only of PH, Fe, Conductivity)	
BD0	Raw effluent	2
BD (1,2)-1	Melt 10%	2
BD (1,2)-2	Melt 15%	2
BD (1,2)-3	Melt 25%	2
BD (1,2)-4	Melt 50%	2
BD (1,2)-5	Melt 100%	2
		<u>12</u>
	Snow Subtotal - Samples	<u>44</u>

C. Aged Snow

CE	Dry Snow	
CE0	Raw influent	1
CE (1,2,3)-1	Melt 10%	3
CE (1,2,3)-2	Melt 15%	3
CE (1,2,3)-3	Melt 25%	3
CE (1,2,3)-4	Melt 50%	3
CE (1,2,3)-5	Melt 100%	3
		<u>16</u>

		<u>No. of Samples To Be Taken</u>
CF	Medium Wet Snow	
CF0	Raw influent	1
CF (1,2,3)-1	Melt 10%	3
CF (1,2,3)-2	Melt 15%	3
CF (1,2,3)-3	Melt 25%	3
CF (1,2,3)-4	Melt 50%	3
CF (1,2,3)-5	Melt 100%	<u>3</u>
		16
	Aged Snow Subtotal - Samples	<u>32</u>
	TOTAL TEST SAMPLES (A,B,C)	<u>95</u>



APPENDIX B
LABORATORY TEST DATA SHEETS

CHEMICAL LABORATORY
LABORATOIRE DE CHIMIE

RECEIVED/RECU : (89.03.06)
COMPLETED/COMPLETE : (89.03.17)

YT.MM.DD
AA.MM.JJ

PAGE
(1)

FROM/DE : [HOLE J.C.]
[555 BOOTH ST ROOM 405]

PROJECT/PROJET : [308601]
REPORT/RAPPORT : [889-1434]

ANALYSIS/ANALYSE : [CHEMICAL]

SECTION : [ORES AND PRECIOUS METALS]

NO. OF/DE DETERMINATIONS : [36]

SAMPLE NUMBER	SAMPLE NAME	DETERMINATIONS			
		FE PPM	PH	PH	PH
[889-07372]	[BB1-1]	1798	1864	3.10	NA
[889-07373]	[BB1-2]	1126		3.19	
[889-07374]	[BB1-3]	399		3.39	
[889-07375]	[BB1-4]	69.4	66.7	3.75	NA
[889-07376]	[BB1-5]	7.2		4.36	
[889-07377]	[BB2-1]	2350		3.05	
[889-07378]	[BB2-2]	758		3.28	
[889-07379]	[BB2-3]	282	271	3.45	NA
[889-07380]	[BB2-4]	69.2	NA	3.81	3.66
[889-07381]	[BB2-5]	3.9		4.57	
[889-07382]	[H5]	178		3.10	
[889-07383]	[BB3-1]	1980		3.04	
[889-07384]	[BB3-2]	1138	NA	3.14	3.04

APPROVED/APPROUVE [J.C. Hole]

ANALYST/ANALYSTE : [CR]

FROM/DE : [HOLE J.C.]
[555 BOOTH ST ROOM 405]

PROJECT/PROJET : [308601]
REPORT/RAPPORT : [B89-1435]

CHEMICAL LABORATORY
LABORATOIRE DE CHIMIE

RECEIVED/RECU : [89.03.06]
[84.04.13]
COMPLETED/COMPLETE : [89.03.17]

ANALYSIS/ANALYSE : [CHEMICAL]

SECTION : [ORES AND PRECIOUS METALS]

NO. OF/DE DETERMINATIONS : [29]

PAG: [1]

SAMPLE NUMBER	SAMPLE NAME	DETERMINATIONS			
		FE PPH	YE PPH	PH	PH
[S89-07385]	[B83-3]	244		3.48	
[S89-07386]	[B83-4]	47.9		3.92	
[S89-07387]	[B83-5]	4.3		4.50	
[S89-07388]	[B81-1]	1960		3.06	
[S89-07389]	[B81-2]	1232	1265	3.15	
[S89-07390]	[B81-3]	410		3.36	
[S89-07391]	[B81-4]	112		3.66	
[S89-07392]	[B81-5]	6.9		4.38	
[S89-07393]	[M4]	722		3.06	
[S89-07394]	[B82-1]	1930		3.04	
[S89-07395]	[B82-2]	1186		3.13	
[S89-07396]	[B82-3]	654	644	3.24	3.16
[S89-07397]	[B82-4]	103		3.59	

APPROVED/APPROUVE [J.C. Hole]

ANALYST/ANALYSTE : [LM]

CHEMICAL LABORATORY
LABORATOIRE DE CHIMIE

RECEIVED/RECU : [89.03.06]
COMPLETED/COMPLETE : [89.03.17]

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FROM/DE : [HOLE J.C.
555 BOOTH ST ROOM 405]

PROJECT/PROJET : [308601]
REPORT/RAPPORT : [889-1436]

ANALYSIS/ANALYSE : [CHEMICAL]

SECTION : [ORES AND PRECIOUS METALS]

NO. OF/DE DETERMINATIONS : [37]

DETERMINATIONS

SAMPLE NAME

SAMPLE
NUMBER

FE PPH	FE PPH	PH	PH
4.4	4.38		
1985	3.01		
1292	3.10		
549	3.26	3.20	
30.7	3.89		
2.2	4.54	4.35	
2.2	3.94	4.45	
540	3.21		
636	3.18		
832	3.15		
590	3.23		
73.8	72.5	3.26	
718	NA	2.99	
		2.97	

APPROVED/APPROUVE [J.C. Hole]

ANALYST/ANALYSTE : [LM]

CHEMICAL LABORATORY
LABORATOIRE DE CHIMIE

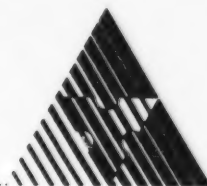
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 PROJECT/PROJET : [308601]
 REPORT/RAPPORT : [389-1445]
 ANALYSIS/ANALYSE : [CHEMICAL]
 SECTION : [ORES AND PRECIOUS METALS]
 RECEIVED/RECU : [89.03.08]
 COMPLETED/COMPLETE : [89.03.17]
 NO. OF/DE DETERMINATIONS : [2]
 PAGE [1]

SAMPLE NUMBER	SAMPLE NAME	DETERMINATIONS	
		FZ PPH	PH
[S89-07456]	[BC 0-1]	314	2.57

APPROVED/APPROUVE [J.C. Hole]

gus

ANALYST/ANALYSTE : [LM,GR]



APPENDIX C
1986 WHISSEL POND - EFFLUENT ANALYSIS

INCO LIMITED
COPPER CLIFF, ONTARIO
CANADA P0M 1N0
FACSIMILE NO. 705-682-8495

FORM: 08-019

PAGE 1 OF 1

DATE: January 30, 1989.

TO: Richard T.C. Cobbold

COMPANY: VECTOR TECHNOLOGIES INC.

FROM: Carolyn MacNeil

INCO LIMITED - Environmental Control

IF THERE ARE ANY PROBLEMS DURING
TRANSMISSION CALL: 705-682-8248

FAX OPERATOR PLEASE COPY TO:

REFERENCE:

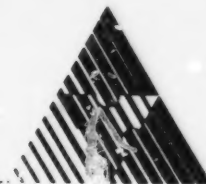
SUBJECT: INCO TAILINGS - Whissel Dam Seepage Station - ICP Analysis

MESSAGE:

These results are from a Scan performed in May 1986 on Whissel Dam Seepage water.
More recent scans are unavailable.

results in milligrams per litre.

Cu - 0.823	Na - 98.0	pH - 2.6
Ni - 27.2	P - 0.167	Suspended Solids - 58
Co - 0.778	Pb - 0.237	NH ₃ - 17.4
Fe - 420	Pt - 0.189	
Ag - less than 0.0023		
Al - 23.7	Rh - 0.0434	
As - 0.0959	Sb - 0.164	
B - 0.276	Se - 0.413	
Ba - 0.0296	Sn - 0.0538	
Be - 0.0109	Te - 0.244	
Bi - 0.126	Ti - 0.0349	
Ca - 571	V - 0.0364	
Cd - 0.0303	Zn - 1.00	
Cr - 0.0783		
Mg - 260		
Mn - 8.80		



APPENDIX D

EXECUTIVE SUMMARY - MOE REPORT ON SNOWFLUENT

EXECUTIVE SUMMARY

The purpose of the study was to determine if the manufacturing of snow from lagoon wastewater was an alternative sewage treatment and storage option. This report presents the results from a two-year joint experimental project sponsored by the Southwest Region of the Ontario Ministry of the Environment and Group Delta, to evaluate the making of snow from lagoon wastewater. Chemical and bacterial information collection about the processes was emphasized, and not the capital or operating costs. These costs have been estimated by the consultant.

This innovative process appears to be an effective sewage treatment and storage option. The concentration of the various chemical pollutants measured in the perimeter ditches containing the site run-off (final effluent) was better than those achieved by conventional tertiary treatment. The maximum concentration measured were BOD5 2 mg/L, total phosphorus 0.08 mg/L, soluble phosphorus 0.05 mg/L, free ammonia 0.1 mg/L, total Kjeldahl nitrogen 0.45 mg/L, and nitrates of 0.01 mg/L. The concentrations of the various bacteria tested, fecal coliforms, fecal streptococci, Pseudomonas aeruginosa and Clostridium perfringens in these perimeter ditches were also at or below detection levels. These low concentrations of both chemical and bacteriological parameters are the result of a combination of instantaneous reactions occurring at the time of snow generation and reductions with time as the snow aged.

The bacterial aerosol produced during the snowmaking was similar to those reported in literature from irrigation systems and secondary waste treatment facilities when levels of indicator bacteria were compared. The recovery of pathogenic bacteria in the aerosol was below the detection limit in most cases. However, significant indicator bacterial reductions in the aerosol concentrations were achieved by pre-disinfection prior to snowmaking. This disinfection did not affect the chemical quality of the snow.